

Conductance of a quantum wire at low electron density

Scientific Achievement

The goal of this project is to develop theoretical understanding of the nature of the electron liquid formed in quantum wires in the regime of low electron density. A number of experiments performed in the US, Europe, and Australia showed that when the density of electrons is very low, the conductance of a high-quality quantum wire develops new features. The most remarkable of such features is the plateau at half of the standard quantized value of conductance observed in several long quantum wires.

The theory is based on the concept of short-range crystalline ordering of electrons in the wire in the regime when the density is very low, and the Coulomb interaction effects are very strong. The spins of the electrons in such a Wigner crystal form a Heisenberg chain, with exchange coupling J that is very small compared to the Fermi energy. When the temperature is much smaller than J , the transport properties of the system are very similar to those of conventional Luttinger liquids. On the other hand, there is a very broad range of intermediate energy scales between J and the Fermi energy. When the temperature is in this range, the propagation of the spin excitations through the wire is strongly suppressed. Subtle differences between quantum wires and idealized theoretical models lead to the violation of the well-known principle of spin-charge separation in one dimension. As a result, the change of the spin dynamics at temperatures above J strongly affects the electric current and reduces the conductance by a factor of 2. This theory is in excellent agreement with experiments.

Significance

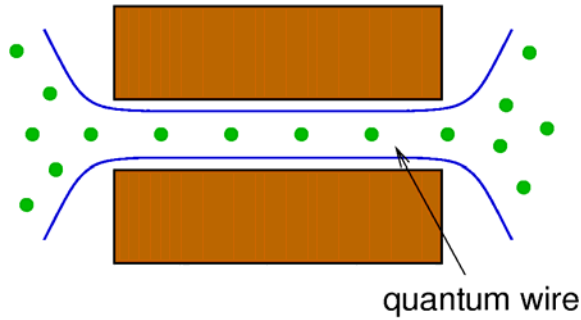
Along with the famous 0.7 anomaly in quantum point contacts, the half-plateau of conductance in quantum wires pointed to the insufficiency of the conventional description of one-dimensional interacting electrons based on the Luttinger model. This work has demonstrated that the latter approach is applicable only in the limit of low temperatures, and that in realistic quantum wires strong deviations from it should be observed. The explanation of the half-plateau provided by this theory is much preferable to the popular attempts based on the hypothesis of spontaneous spin polarization in one-dimensional systems, which was theoretically disproved decades ago. These ideas also give insight into the 0.7 anomaly in quantum point contacts.

The existence of a broad range of energies where Luttinger liquid theory is not applicable is very interesting from theoretical point of view, as indicated by recent publications stimulated in part by this work. The author was invited to a number of conferences to give talks on the subject, including the prestigious Gordon conference. This work has been published in Phys. Rev. Lett. 92, 106801 (2004) and Phys. Rev. B 70, 245319 (2004). Future plans include treatment of quantum point contacts and the case of multi-row crystals.

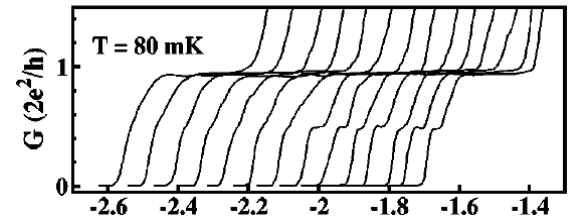
Performers

K. A. Matveev (ANL-MSD)

Conductance of a quantum wire at low electron density

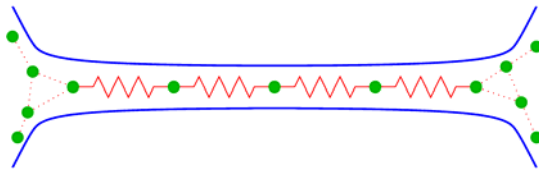


Several experiments show a mini-plateau of conductance at half of the standard value



Thomas *et al.* (Cambridge)

Our theory models the electron system in the wire by a Wigner crystal:



The spins of electrons inside the wire form a spin chain with very weak exchange coupling. Transmission of spin excitations through the wire is suppressed at higher temperatures, leading to the reduction of conductance.

Results

1. Low temperature: $T \ll J$

$$G = \frac{2e^2}{h} \quad (\text{full plateau})$$

2. High temperature: $T \gg J$

$$G = \frac{e^2}{h} \quad (\text{half-plateau})$$